HYDRAIN - INTEGRATED DRAINAGE DESIGN COMPUTER SYSTEM

VOLUME VI. HYCHL - ROADSIDE CHANNELS

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INTRODUCTION

This document discusses the HYCHL computer program. HYCHL assists in designing stable roadside channel and irregular channel riprap linings. The channel lining stability analysis uses permissible shear stress. The bases for program algorithms are the Federal Highway Administration (FHWA) publications Hydraulic Engineering Circular 15 (HEC-15) and HEC-11.[1, 2]

When provided design flow and channel conditions (i.e., slope, shape, and lining type), HYCHL can analyze drainage channels for stability. The HYCHL program determines stability through application of tractive force theory. The tractive force theory compares shear exerted on the lining, as a result of flow, with the permissible shear stress of the lining. HYCHL also calculates the maximum discharge a particular channel can convey given permissible shear stress and the corresponding allowable depth. HYCHL can analyze all linings with a known permissible shear for both stability and maximum discharge. The output generated by HYCHL includes flow depth, velocity, calculated shear stress, permissible shear stress, and maximum discharge.

HYCHL capabilities allow analysis of lining having both rigid and flexible composition. Flexible lining installation can be on a temporary or permanent basis. The lining can consist of a single material or a composite set of materials (i.e., a paved low flow channel section with a vegetative upper channel section). HYCHL allows analysis of both straight and curved channel segments. The channel shape can consist of regular and irregular profiles. The channel flow can be either a constant or variable throughout the channel length. (Variable channel flow recognizes that runoff enters the channel, increasing flow.)

The remaining document provides a more detailed explanation of HYCHL capabilities. The next section provides an overview of the components that form the HYCHL program. The third section describes the technical information incorporated into HYCHL. The information includes all relevant equations from HEC-15, HEC-11, and other sources in the literature. The fourth section provides instruction and commentary on the HYCHL program, input data, commands, and support programs. Three appendixes provide examples of HYCHL applications, general descriptions of typical applications, and explanations of the HYCHL commands.

SYSTEM OVERVIEW

HYCHL represents a consolidation of analysis and design techniques presented in HEC-15 and HEC-11.[1, 2] Although both documents are directed towards the analysis of lining stability, each document addresses different classes of problems. HEC-15 focuses on linings in roadside channels which are characterized by relatively uniform cross sections on a constant slope. Alternatively, HEC-11 addresses natural channels with irregular cross sections, varying bottom slopes, and generally carrying larger flows. HEC-11 focuses on the design of riprap lining in such cases. Together, HEC-15 and HEC-11 provide a series of analysis and design tools that are present in HYCHL.

RIGID, VEGETATIVE, GABION, AND TEMPORARY LININGS

HEC-15 outlines procedures for analyzing channel linings based on tractive force theory. The procedure involves comparing an estimated shear stress resulting from flow in a channel to the maximum permissible shear stress determined for a given lining type. If the shear from flowing water increases to the point where it is greater than the permissible shear of the lining, failure may occur. This concept allows for calculation of the maximum discharge a channel can convey, when the calculated shear is assumed to equal permissible shear.

The analysis of rigid, vegetative, gabion, and temporary linings in HYCHL is applicable to channels of uniform cross section and constant bottom slope. Roadside channels typically exhibit such characteristics. HYCHL offers a variety of design and analysis options including:

- Rigid or flexible linings.
- Temporary or permanent linings.
- Single or composite linings.
- Straight or bend channel sections.
- Alternative regular channel shapes.
- Constant or variable channel flow.

Depending on channel function, material availability, costs, aesthetics, and desired service life, a designer may choose from a variety of lining types. Rigid linings in HYCHL include concrete, grouted riprap, stone masonry, soil cement, and asphalt. Flexible linings in HYCHL include those which may be considered permanent and those considered temporary. Permanent flexible linings include vegetation, riprap, and gabions. Temporary linings include woven paper, jute mesh, fiberglass roving, straw with net, curled wood mat, synthetic mat, and bare soil (unlined).

HYCHL provides for the analysis of all of these lining types individually and when two linings are specified together as a composite lining. Composite linings are typically designed with a low flow lining protecting the bottom of a channel where higher shear stresses are anticipated and a side slope lining protecting the channel sides. Composite linings are used when lining side slopes with the same material applied to the bottom is undesirable for reasons of economics, aesthetics, or safety.

The designer of rigid, vegetative, and temporary linings may apply HYCHL to a variety of geometric configurations. HYCHL calculates the shear stresses on linings in straight channel sections as well as the higher stresses found in bend sections. Channel cross sections available in HYCHL for these lining types are trapezoidal, parabolic, triangular, and triangular with rounded bottom.

Finally, the performance of rigid, vegetative, gabion, and temporary linings can be evaluated using a design flow which is assumed to be constant for the entire channel length or a variable inflow. The variable inflow is characterized as a uniform lineal flow that results in an increasing discharge with channel length. Under such conditions, HYCHL provides the designer with an estimate of the length of channel for which a given lining may be suitable.

HEC-15 includes limited guidance, for the analysis of gabion linings on steep slopes (10 to 25 percent), but provides no guidance on any other conditions. Therefore, calculating shear stress for gabion linings follows the same methodologies as described for riprap in HEC-15, using the D_{50} for the gabion fill material. This assumes that the wire enclosure does not significantly affect the roughness of the lining. This assumption is supported by prior research.[3]

RIPRAP LININGS

HEC-15 and HEC-11 both outline procedures for analyzing riprap-lined channels. These procedures are based on the same logic (i.e., the tractive force theory), but include additional considerations not necessary for analyzing rigid, vegetative, gabion, and temporary lining types. Although HEC-15 is recommended for design flows less than 1.4 m^3/s, and HEC-11 for flows in excess of 1.4 m^3/s, the same basic principles are used in deriving the analysis/design equations in these documents. The tractive force procedure is applied to develop the riprap analysis and design procedures used in HYCHL.

A channel lined with riprap can be analyzed for stability given the riprap size, or the riprap size can be determined based on a user-supplied stability factor. Composite channels which have riprap for the low flow lining and another lining type for the high-flow channel can be analyzed. HYCHL can also analyze irregular channel shapes which are lined with riprap only.

Riprap-lined channels base most hydraulic calculations on Manning's equation. An exception occurs in cases where the flow depth is small compared to a characteristic riprap size such that the effects of the rock protruding into the flow field cannot be ignored. Such conditions may occur, for example, on steep slopes. The Bathurst hydraulic procedure given in HEC-15 is applied in this case to determine the flow depth and velocity in a given channel.

TECHNICAL INFORMATION

This section provides technical descriptions of the key methodologies implemented in HYCHL. The theory and practice of analyzing and designing rigid, vegetative, temporary linings, and gabion linings as applied in HYCHL is provided. This is followed by additional considerations necessary for the analysis and design of riprap linings.

RIGID, VEGETATIVE, GABION, AND TEMPORARY LININGS

The analysis and design of rigid, vegetative, gabion, and temporary linings in channels of constant cross section and slope, typical of roadside channels, is accomplished in HYCHL by the application of tractive force theory. The procedure used to analyze temporary linings is identical to that applied for permanent linings. However, since temporary linings are intended to have a shorter service life, the design flow may be lower. The hydraulic characterization of the channel flow and the calculation of the shear stresses is presented for a variety of lining types and channel configurations.

Calculated Shear Stress

Most roadside channels carry uniform flow that can be represented by Manning's formula. For analysis and design purposes, uniform flow conditions are assumed with the energy slope approximately equal to average bed slope. By making this assumption, flow conditions can be defined by a uniform flow equation such as Manning's equation. This section discusses how to estimate Manning's friction factor, for both single and composite channels, and how to solve for depth from the Manning's equation.

The first set of linings to address is temporary linings. These include: woven paper, jute mesh, fiberglass roving, straw with net, curled wood mat, and synthetic mat. The Manning's n value for these linings is defined by the following equation:

$$n = \frac{R_h^{\frac{1}{6}}}{\left[3.13 \times \left[a + b \times \log\left(\frac{R_h}{K_s} \right) \right] \right]} \tag{1}$$

Where:

n	=	Manning's n.
R_h	=	Channel hydraulic radius, m.
K_s	=	Roughness element height, m, summarized in table 1.
a, b	=	Dimensionless empirical coefficients associated with each lining summarized in table 1.

Table 1. Empirical coefficients for temporary linings.

Lining Material	K_s (mm)	a	b
Woven Paper	1.2	0.73	8.00
Jute Mesh	11.6	0.74	8.04
Fiberglass Roving	10.7	0.73	8.00
Straw with Net	36.6	0.72	7.83
Curled Wood Mat	33.5	0.65	1.20
Synthetic Mat	19.8	0.96	8.13

For values of R_h/K_s less than one, n becomes negative when using equation (1). To avoid this situation, an upper limit is placed on n. For a given lining type, the maximum n is computed when the hydraulic radius is 10 percent greater than the hydraulic radius which would result in the denominator of equation (1) equaling zero. This quantity is denoted as R_o. Therefore, for all values of hydraulic radius less than $1.1 \times R_o$, Manning's n remains the same.

For vegetative linings, n is dependent upon the physical characteristics of the vegetation as well as the shear stress exerted on the grass. It is a function of physical channel parameters, average grass height, and stiffness. The following equation is used to estimate n for vegetative linings:

$$n = \frac{R_h^{\frac{1}{6}}}{19.91 \times log\left[44.8 \times R_h^{1.4} \times S^{0.4} \times h^{0.6} \times MEI^{-0.4}\right]} \tag{2}$$

Where:

R_h	=	Hydraulic radius, m.
S	=	Slope, m/m.
h	=	Average grass height, m.
MEI	=	Stiffness, N×m^2.

Values of h and MEI for the five different classifications of retardance (A - E) are empirical coefficients associated with each lining and are shown in table 2. The classification is a user input which determines the channel roughness for the particular vegetative lining.

Table 2. Relative roughness parameters for vegetation.

Retardance Class	Average Height, h (mm)	Stiffness, MEI (N x m^2)
A	920	300
B	610	20
C	200	0.5
D	100	0.05
E	40	0.005

Bare soil (considered to be a temporary lining) and rigid linings exhibit Manning's n values that are a function of flow depth. Table 3 shows the n values that HYCHL uses for these linings. Linear interpolation is used to smooth transition between various depth ranges.

Table 3. Manning's roughness coefficients for rigid and bare soil linings.

Lining Type	Depth Ranges				
meter	d ≤ 0.15	0.15 < d ≤ 0.20	0.20 < d ≤ 0.60	0.60 < d < 0.65	d ≥ 0.65
Rigid Concrete	0.015	Linear Interpolation	0.013	Linear Interpolation	0.013
Grouted Riprap	0.040		0.030		0.028
Stone Masonry	0.042		0.032		0.030
Soil Cement	0.025		0.022		0.020
Asphalt	0.018		0.016		0.016
Unlined Bare Soil	0.023		0.020		0.020

If the channel lining is composite, roughness values for each lining are determined and an effective **n**-value is calculated. The effective **n**-value for a composite lining is defined by the following relationship:

$$n_E = \left[\frac{P_L}{P} + \left(1 - \frac{P_L}{P} \right) \times \left(\frac{n_S}{n_L} \right)^{\frac{3}{2}} \right]^{\frac{2}{3}} \times n_L \tag{3}$$

Where:

n_E	=	Effective Manning's **n**-value.
P_L	=	Low-flow perimeter, m.
P	=	Total perimeter, m.
n_S	=	Manning's roughness value for side slope lining.
n_L	=	Manning's roughness value for low flow lining.

This equation reduces to $\mathbf{n_E} = \mathbf{n_L}$ for channels that have a flow depth less than the lining transition depth. In this case, $\mathbf{P_L} = \mathbf{P}$ and the effective Manning's **n**-value equals the low flow lining **n**-value. The lining is effectively treated as a single lining. The user has the option of supplying **n**-values for one or both linings, otherwise, the program computes roughness.

Normal depth is calculated using an iterative process beginning with an initial estimate for depth. HYCHL calculates the geometric parameters (area, wetted perimeter, and top width) and Manning's **n**-value based on the initial depth. The equation for calculating flow values combines Manning's equation and the continuity equation:

$$Q_i = \frac{1}{n_E} \times A_i \times R_{h_i}^{\frac{2}{3}} \times S_f^{\frac{1}{2}} \tag{4}$$

Where:

Q_i	=	Flow in channel for depth estimate, m^3/s.
A_i	=	Flow area of channel for depth estimate, m^2.
R_{hi}	=	Hydraulic radius for depth estimate, m.
S_f	=	Friction slope of channel, m/m.

The iteration process continues until the estimated flow, $\mathbf{Q_i}$ calculated from an assumed depth is within 0.1 percent of the given design flow, $\mathbf{Q_D}$. Until this is achieved, successive estimates of depth are calculated from the following equation:

$$d_{i+1} = \left[\frac{d_i + \frac{Q_D}{Q_i} \times d_i}{2} \right] \tag{5}$$

Where:

d_i = Estimated depth at iteration **i**, m.
d_{i+1} = Estimated depth at iteration i+1.

Once the flow depth is established, the analytical relationships summarized in figure 1 are applied to calculate area, wetted perimeter, and top width for the regular channel shapes. These parameters are calculated numerically for irregular channel shapes. Once the depth has been calculated, shear stress for the channel bottom is obtained from the following equation:

$$\tau_c = \gamma \times d_{MAX} \times S_F \tag{6}$$

Where:

τ_c = Calculated shear stress on the channel bottom, N/m^2.
γ = Specific weight of water, N/m^3.
d_{MAX} = Normal depth, m.
S_F = Friction slope, m/m.

<u>Permissible Shear Stress</u>

Shear stress is the force exerted on the lining by flowing water per unit area of the lining. Each lining has associated with it a permissible shear stress, τ_p. Most of the permissible shear values come from tables or charts in HEC-15 and are considered conservative, that is, they are appropriate for design purposes. Table 4 summarizes the permissible shear stress values.

For rigid linings, table 4 shows that the permissible shear stress approaches infinity. For purposes of evaluating failure resulting from tractive forces this is a reasonable assumption for rigid linings in good condition.

If the channel is lined with a **gabion mattress**, the permissible shear stress is the larger value obtained from the following two equations:

$$\tau_p = 359.1 \times D_{50} \tag{7}$$

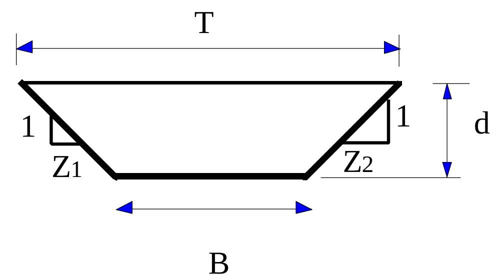
$$\tau_p = 51.2 \times MT + 177.2 \tag{8}$$

Trapezoidal or V-Shaped

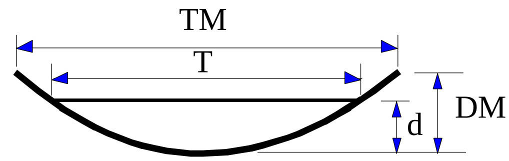
$$A = Bd + ½d^2 (Z_1 + Z_2)$$

$$P = B + d\sqrt{Z_1^2 + 1} + d\sqrt{Z_2^2 + 1}$$

$$T = B + d\,Z_1 + d\,Z_2$$



Parabolic



$$K = 4\frac{(DM)}{(TM^2)}$$

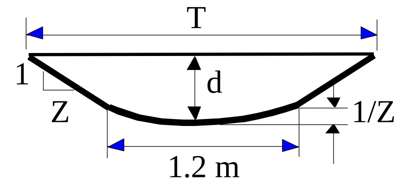
$$A = 2/3\ Td$$

$$T = \sqrt{\frac{4d}{K}}$$

$$P = 1/2\sqrt{16d^2 + T^2} + \left(\frac{T^2}{8d}\right)\ln_e\left(\frac{4d + \sqrt{16d^2 + T^2}}{T}\right)$$

V-Shaped with Rounded Bottom

(Two Cases)



1) $d \le \frac{1}{Z}$

$$A = 1.472\,d\sqrt{dZ}$$

$$T = 2.208\sqrt{dZ}$$

$$P = 0.610\,Z\ln_e\left(\frac{d}{0.305\,Z} + \sqrt{1 + \frac{d}{0.305Z}}\right) + 0.610\sqrt{\left(\frac{d}{0.305}\right)^Z + \frac{dZ}{0.305}}$$

2) $d > \frac{1}{Z}$

$$A = 0.248Z + 0.372\left(\frac{d}{0.305} - \frac{1}{Z}\right) + 0.093Z\left(1 - \frac{1}{Z}\right)^2$$

$$T = 0.610Z\left(\frac{d}{0.305} + \frac{1}{Z}\right)$$

$$P = 0.610Z\ln_e\left(\frac{1}{Z} + \frac{\sqrt{Z^2 + 1}}{Z}\right) + 0.610\frac{(1 + Z^2)}{Z} + 0.610\left(\frac{d}{0.305} - \frac{1}{Z}\right)\sqrt{1 + Z^2}$$

Figure 1. Equations for regular channel shapes.

Table 4. Permissible shear stresses for lining materials.

Lining Category	Lining Type	Permissible Shear Stress (N/m^2)
Temporary	Woven Paper Net	7.2
	Jute Net	21.5
	Fiberglass Roving:	
	Single	28.7
	Double	40.7
	Straw with Net	69.4
	Curled Wood Mat	74.2
	Synthetic Mat	95.8
	Soils	variable
Vegetative	Class A	177.2
	Class B	100.6
	Class C	47.9
	Class D	28.7
	Class E	16.8
Rigid	Concrete	approaches ∞
	Grouted Riprap	approaches ∞
	Stone Masonry	approaches ∞
	Soil Cement	approaches ∞
	Asphalt	approaches ∞

Where:

D_{50} = Median rock diameter, m.
MT = Mattress thickness, m.

Equations (7) and (8) are obtained from HEC-15 Charts 23 and 24, respectively. Notice that equation (7) is dependent on D_{50} and equation (8) is dependent on mattress thickness.

For a **noncohesive soil** lining, equation (9) defines the permissible shear stress value:

$$\tau_p = 801.1 \times D_{50} \tag{9}$$

Where:

τ_p = Permissible shear stress of soil, N/m^2.
D_{50} = Mean soil particle diameter, m.

Permissible shear stress of **cohesive soils** is dependent on soil type and a plasticity index and is determined from one of the following three equations:

Loose,	$\tau_p = 0.1628 \times PI^{0.84}$	(10)
Medium Compact,	$\tau_p = 0.2011 \times PI^{1.071}$	(11)
Compact,	$\tau_p = 0.2729 \times PI^{1.26}$	(12)

Where:

PI = Plasticity index of soil.

The user may override computation of permissible shear stress as discussed above by supplying a user input value for the permissible shear stress of a lining. The permissible shear stress can be input for both the low flow lining as well as the side slope lining of composite channels.

The ratio of permissible shear stress to calculated shear stress can be called the stability factor. For roadside channels, or other uniform channels, where hydraulic conditions are consistent, a channel design can be considered stable when the stability factor is greater than one.

Side Shear

Channel side slopes are also subject to shear and in some cases may limit selection of linings. Side shear is analyzed by use of the parameter, $\mathbf{K_{SIDE}}$. $\mathbf{K_{SIDE}}$ is the ratio of maximum channel side shear to channel bottom shear. It is a function solely of channel shape. It is dependent on channel geometry and channel side slopes. Figure 2 displays a schematic of shear stress distribution for a trapezoidal channel. The maximum shear stress on the side slope will always be less than or equal to that on the bottom.

Taken from Anderson, figures 3 and 4 are used to obtain $\mathbf{K_{SIDE}}$ for trapezoidal and V-shaped channels, respectively.(4) The other two shapes, parabolic and V-shaped with rounded bottom, are assumed to require a $\mathbf{K_{SIDE}}$ value equal to 1.0 because these shapes have no clear distinction between side slopes and base of channel. This conservative assumption implies that the maximum side shear occurs at a point directly adjacent to the deepest point and must resist the same shear as the deepest point in the channel. Setting side shear equal to bottom shear yields $\mathbf{K_{SIDE}}$ value equal to 1.0.

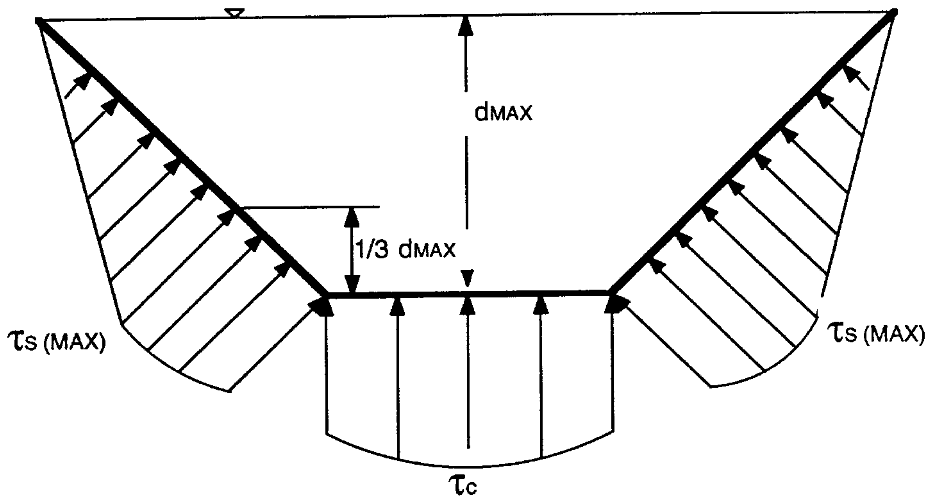


Figure 2. Assumed shear stress distribution.

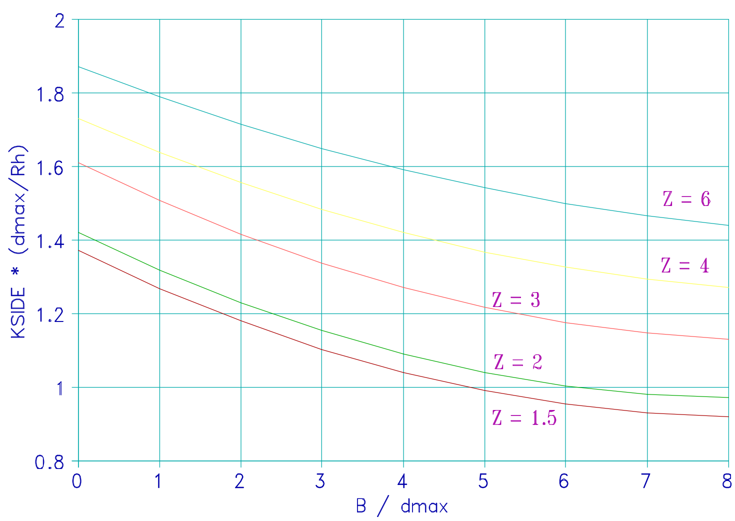


Figure 3. Maximum boundary shear stress on sides of trapezoidal channels.

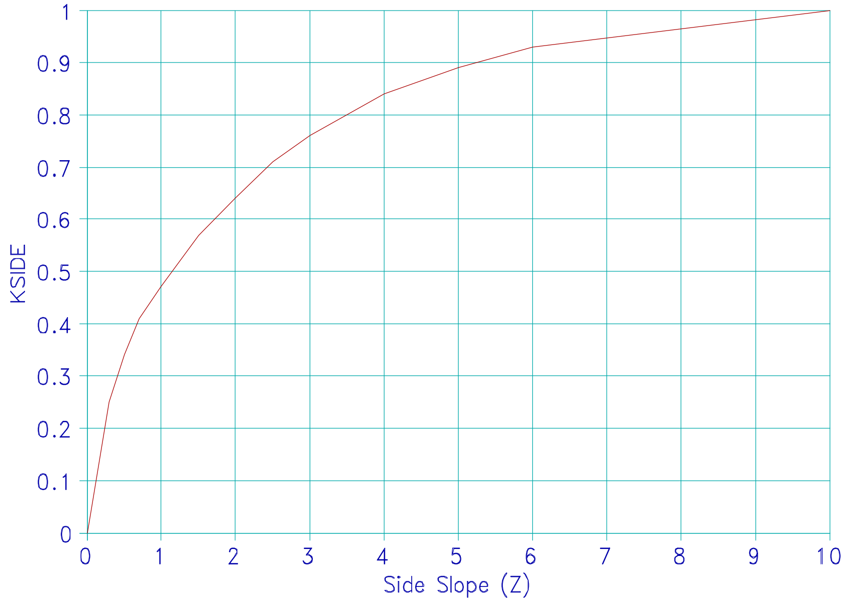


Figure 4. Ratio of side to bottom shear stress for triangular channels.

Since $\mathbf{K_{SIDE}}$ is always less than or equal to one, side shear does not limit the design of a single, rigid, vegetative, gabion, or temporary lining, but may affect the design of composite linings. For the side slope or upper lining in a composite design, the parameter $\mathbf{K_{SU}}$ must be defined. It is a function of both channel shape and lining transition height, $\mathbf{h_{TL}}$. Maximum side shear for the side slope lining occurs at the lining transition point (the most submerged point of the side slope lining).

Table 5 summarizes the derivation of side shear ratios for estimating side shear. For single linings or for channels with composite linings with a maximum flow depth less than the lining transition depth, the side shear ratio is developed as previous described. However, if the flow depth in a compositely lined channel is greater than the lining transition height, then the parameter $\mathbf{K_{SU}}$ must be calculated and used as the side shear ratio for evaluating the upper lining.

Table 5. Derivation of side shear ratios.

	Single Lining	Composite Lining		
Shape	All Cases	$d_{MAX} < h_{TL}$ Lower Lining	$d_{MAX} \geq h_{TL} \geq 1/3d_{MAX}$ Upper Lining	$1/3d_{MAX} > h_{TL}$ Upper Lining
Trapezoidal	K_{SIDE} from figure 3	K_{SIDE} from figure 3	K_{SU} from equation 14	$K_{SU} = K_{SIDE}$ from figure 3
V-Shaped	K_{SIDE} from figure 4	K_{SIDE} from figure 4	K_{SU} from equation 14	$K_{SU} = K_{SIDE}$ from figure 4
Parabolic	$K_{SIDE} = 1.0$	$K_{SIDE} = 1.0$	K_{SU} from equation 13	K_{SU} from equation 13
V-shaped w/rounded bottom	$K_{SIDE} = 1.0$	$K_{SIDE} = 1.0$	K_{SU} from equation 13	K_{SU} from equation 13

If the channel is parabolic or V-shaped with rounded bottom, shear stress at every point in the channel is a function of flow depth above that point where shear equals $\gamma \times \mathbf{d_{MAX}} \times \mathbf{S_F}$. Since the depth of water above the lining transition is ($\mathbf{d_{MAX}} - \mathbf{h_{TL}}$), then $\mathbf{K_{SU}}$ is defined by the following equation:

$$K_{SU} = \frac{\gamma \times (d_{MAX} - h_{TL}) \times S_F}{\gamma \times d_{MAX} \times S_F} = \frac{d_{MAX} - h_{TL}}{d_{MAX}} \qquad (13)$$

For compositely lined trapezoidal or V-shaped channels with a submerged lining transition height, K_{SU} further depends on whether one third of d_{MAX} (see figure 2) is above or below the lining transition height. If the lining transition depth, h_{TL}, is below one third of the maximum depth, the lining at the transition experiences the maximum side shear and K_{SU} equals K_{SIDE}. However, if the lining transition depth is above the depth of maximum side shear (one third d_{max}), then K_{SU} is calculated using the following equation:

$$K_{SU} = \frac{3}{2} \times \left(\frac{d_{MAX} - h_{TL}}{d_{MAX}} \right) \times K_{SIDE} \qquad (14)$$

$\mathbf{K_{SU}}$ is used to calculate the maximum shear on an upper lining. Stability is determined by comparing τ_s to τ_p for the side slope lining. The equation for τ_s is:

$$\tau_s = K_{SU} \times \gamma \times d_{MAX} \times S_F \qquad (15)$$

Bends

A channel bend causes additional shear stresses because of centrifugal forces. These additional stresses are taken into account by calculating a bend factor, $\mathbf{K_B}$, to determine bend shear. This factor represents the ratio of bend shear to the amount of shear in the same straight channel section. $\mathbf{K_B}$ is a function of a characteristic width of the channel and its radius of curvature. Base width, **B**, is used as the characteristic width for trapezoidal channels. The bend shear curve is approximated by the following parabolic equation derived from HEC-15 (chart 10):

$$K_B = 2.38 - 0.206 \times \left(\frac{R_c}{B} \right) + 0.0073 \times \left(\frac{R_c}{B} \right)^2 \tag{16}$$

Where:

K_B	=	Bend shear factor, dimensionless.
R_c	=	Radius of curvature, m.
B	=	Characteristic width of channel, m.

Equation (16) is applicable for R_c/B values from 2.0 to 10.0. For values less than 2.0 and greater than 10.0, $\mathbf{K_B}$ is set to 2.00 and 1.05, respectively. For channel shapes other than trapezoids, the characteristic width, **B**, is calculated as the flow area divided by the maximum depth.

The calculated shear stress in the bend is computed by multiplying the shear stress value in the straight channel section by the bend shear factor:

$$\tau_{c,B} = \tau_{c,S} \times K_B \tag{17}$$

Where:

$\tau_{c,B}$	=	Calculated shear in the bend for the bottom or side slopes, N/m^2.
$\tau_{c,S}$	=	Calculated shear for bottom or side slopes in the straight channel section, N/m^2.

The added stress resulting from a bend does not require the use of more resistant linings for the entire straight portion of a channel. The necessary length of protection is defined by the following equation:

$$L_p = 0.7350 \times \left[\frac{R_h^{\frac{7}{6}}}{n} \right] \tag{18}$$

Where:

R_h	=	Hydraulic radius, m.
n	=	Manning's **n**.
L_p	=	Length of protection, m.

Since the water surface is no longer level across the channel in a bend, additional freeboard must be provided. The minimum necessary freeboard is calculated using the following equation for superelevation.

$$SE = \frac{V^2 \times T}{g \times R_c} \tag{19}$$

Where:

V	=	Average velocity, m/s.
T	=	Top width, m.
R_c	=	Radius of curvature, m.
SE	=	Superelevation, m.
g	=	Gravitational constant, m/s^2.

<u>Maximum Discharge</u>

The stability of rigid, vegetative, gabion, and temporary linings is evaluated based on a comparison of permissible and calculated shear stress. The maximum discharge a channel can convey for a given lining is calculated by setting calculated shear equal to permissible shear. The allowable flow depth for the lining is then found from the following equation:

$$d_{QMAX} = \frac{\tau_p}{\gamma \times S_F} \tag{20}$$

Where:

d_{QMAX}	=	The largest flow depth that the lining can support, m.

At this depth, the calculated shear stress is exactly equal to the permissible shear stress. This depth is used to calculate flow from Manning's equation, which is combined with the continuity equation, Q = A × V, to compute maximum discharge.

$$Q_{MAX} = \frac{1.49}{n_E} \times A \times R_h^{\frac{2}{3}} \times S_F^{\frac{1}{2}} \tag{21}$$

Where:

Q_{MAX}	=	Maximum discharge, m^3/s.
A	=	Flow area, m^2.
R_h	=	Hydraulic radius, m.
S_F	=	Friction slope, m/m.
n_E	=	Effective Manning's **n**.

If a channel is compositely lined, the limiting flow depths corresponding to each of the two linings are estimated. The maximum depth for the low flow lining is defined by equation (20). The maximum depth for the side slope lining must also be calculated. If the channel is V-shaped or trapezoidal, then the maximum depth of water is dependent on $\mathbf{K_{SIDE}}$, the side shear ratio. The shapes are differentiated because parabolic and V-shaped with rounded bottom channels have gradually varying cross sections. The following equation calculates a maximum depth for stability of V-shaped or trapezoidal channels if lining transition height, h_{TL}, is greater than one third the maximum flow depth:

$$d_{SIDE} = h_{TL} + \frac{\tau_{p,ss}}{\gamma \times S_F \times \frac{3}{2} \times K_{SIDE}} \tag{22}$$

Where:

d_{SIDE}	=	Maximum depth of channel for side slope lining stability, m.
h_{TL}	=	Lining transition height, m.
$\tau_{p,ss}$	=	Side slope permissible shear stress, N/m^2.
γ	=	Unit weight of water, N/m^3.
S_F	=	Friction slope, m/m.
K_{SIDE}	=	Side shear ratio.

For V-shaped or trapezoidal channels whose lining transition depth is less than one third the flow depth, the maximum depth for side slope stability is calculated as:

$$d_{SIDE} = \frac{\tau_{p,s}}{\gamma \times S_F \times K_{SIDE}} \tag{23}$$

If the shape is parabolic or V-shaped with a rounded bottom, then the depth of water is calculated by the following equation:

$$d_{SIDE} = h_{TL} + \frac{\tau_{p,s}}{\gamma \times S_F} \tag{24}$$

Once the maximum flow depths of both linings are computed, $\mathbf{Q_{MAX}}$, is computed from Manning's equation using that value for the limiting (shallower) depth. From $\mathbf{Q_{MAX}}$, the maximum stable length of a channel is calculated for a given lateral inflow, **q**. Lateral inflow contribution is an optional input, and if given, then maximum length, $\mathbf{L_{MAX}}$, is calculated according to the following equation:

$$L_{MAX} = \frac{Q_{MAX}}{q} \tag{25}$$

RIPRAP LININGS

Although based on the same underlying principles of tractive force theory, riprap linings have been presented by themselves to highlight their design process. Both HEC-11 and HEC-15 address components of riprap lining design under different flow conditions and channel types. HYCHL assists the designer by automatically recognizing the appropriate conditions and employing the applicable lining design procedures for riprap-lined channels. This section discusses topics which are specific to riprap linings.

Estimating Manning's Roughness Coefficient

Manning's roughness coefficient, **n**, is based on the channel flow regime and user preferences. HYCHL default calculations determine an **n** value based on the ratio of the average depth to the median riprap size. However, if d_a/D_{50} is greater than 30,000, the procedures may not apply. For ratios greater than or equal to 2 and less than or equal to 185 then equation (26) applies:[4]

$$n = \frac{4.657 \times R_h^{\frac{1}{6}}}{32.25 + 5.23 \times \log\left(\frac{R_h}{D_{50}}\right)} \tag{26}$$

Where:

n	=	Manning's **n**.
R_h	=	Hydraulic radius, m.
D_{50}	=	Median riprap size, m.
d_a	=	Average flow depth, m.

For values of R_h/D_{50} less than one, **n** becomes negative when using equation (26). To avoid this situation, an upper limit is placed on **n**. For a given riprap size, the maximum **n** is computed when the hydraulic radius is 10 percent greater than the hydraulic radius which would result in the denominator of equation (26) equaling zero. This quantity is denoted as R_o. Therefore, for all values of hydraulic radius less than $1.1 \times R_o$, Manning's **n** remains the same.

For ratios of d_a/D_{50} of greater than 185, equation (27) applies:

$$n = 0.0232 \times d_a^{\frac{1}{6}} \tag{27}$$

If a riprap or gabion-lined channel has a value of $\mathbf{d_a}/D_{50}$ less than two, then the Bathurst procedure is used to estimate the hydraulic conditions.[5] When riprap protrudes into the flow field, very complex flow conditions are created which significantly increases flow resistance due to Froude number effects, i.e., standing waves, hydraulic jumps, and free surface drag. The Bathurst resistance equation is used in the program to quantify these effects in computing channel hydraulics. Bathurst's work is based on laboratory experiments with d_a/D_{50} values ranging from 0.3 to 8.0.

The following form of the Bathurst equation is used:

$$\frac{V}{\sqrt{g \times d_a \times S_F}} = f_n(FR) \times f_n(REG) \times f_n(CG) \tag{28}$$

Where:

V	=	Mean velocity, m/s.
g	=	Gravity constant which equals 9.81 m/s^2.
S_F	=	Friction slope, m/m.
d_a	=	Average flow depth, m.
FR	=	Froude number = $V/(g \times d_a)^{1/2}$.
REG	=	Roughness element geometry.
CG	=	Channel geometry.

The functions of Froude number, roughness element geometry, and channel geometry are given by the following equations:

$$f_n(FR) = \left[\frac{0.28}{b} \times FR\right]^{\log\left(\frac{0.755}{b}\right)} \tag{29}$$

$$f_n(REG) = 13.434 \times \left[\frac{T}{D_{50}}\right]^{0.492} \times b^{\left[1.025 \times \left(\frac{T}{D_{50}}\right)^{0.118}\right]} \tag{30}$$

$$f_n(CG) = \left[\frac{T}{d_a}\right]^{-b} \tag{31}$$

Where:

T	=	Channel top width, m.
b	=	Parameter describing the effective roughness concentration.
D_{50}	=	Median diameter of riprap, m.

The parameter, **b**, describes the relationship between effective roughness concentration and relative submergence of the roughness bed. This relationship is given by:

$$b = a \times \left[\frac{d_a}{D_{50}}\right]^c \tag{32}$$

Where:

a	=	Parameter varying with channel shape and bed material gradation.
c	=	Parameter varying with bed material gradation.

The parameter, **c**, is a function of the roughness size distribution and varies with respect to the bed-material gradation,   , where:

$$c = 0.648 \times {}^{-0.134} \tag{33}$$

The bed-material gradation is calculated as the log standard deviation of the size distribution. For standard riprap gradations, it is assumed to be constant at a value of 0.182, giving a **c** value of 0.814.

The parameter, **a**, is a function of channel width and bed material size in the cross stream direction, and defined by equation (34):

$$a^{\frac{1}{c}} = 1.175 \times \left[\frac{D_{50}}{T}\right]^{0.557} \tag{34}$$

Since mean velocity, **V**, Froude number, **FR**, roughness element geometry, **REG**, and channel geometry, **CG**, are all implicit functions of mean flow depth, the flow depth must be calculated through iterative solutions of the Bathurst equation. A convergence criterion, similar to the normal depth convergence scheme, is used such that convergence is reached when the left hand side of equation (28) is within 0.1 percent of the right-hand side of the equation. If they are not equal, then depth is incremented or decremented according to the ratio of left side to right side.

HYCHL allows the user to override the default calculations of Manning's **n**. Regardless of the d_a/D_{50} ratio, the user may specify that a user-supplied value, equation (26), or the Anderson equation be used.[6] The Anderson equation is as follows:

$$n = 0.0481 \times D_{50}^{\frac{1}{6}} \tag{35}$$

The stability of the riprap is not determined using the moment analysis which is illustrated in appendix C of HEC-15. Riprap stability is based on the tractive force theory and is calculated according to the equations in the Channel Bottom Shear and Side Shear sections.

Selection of a stability factor for riprap design is left to user judgment based on knowledge of the channel conditions. HEC-11 provides guidelines for the selection of a stability factor which are shown in table 6.

Table 6. Guidelines for the selection of stability factors.

Condition	Stability Factor Range
Uniform flow; Straight or mildly curving reach (curve radius/ channel width > 30); Impact from wave action and floating debris is minimal; Little or no uncertainty in design parameters.	1.0 - 1.2
Gradually varying flow; Moderate bend curvature (30 > curve radius/channel width > 10); Impact from waves or floating debris moderate.	1.3 - 1.6
Approaching rapidly varying flow; Sharp bend curvature (10 > curve radius/channel width); Significant impact potential from floating debris and/or ice; Significant wind and/or boat generated waves 0.30 - 0.61 m; High flow turbulence; Turbulently mixing flow at bridge abutments; significant uncertainty in design parameters.	1.6 - 2.0

Channel Bottom Shear

The stability factor is defined as the ratio of the riprap material's critical, or permissible, shear stress, τ_p, to the tractive force exerted by the flow, τ_c. The shear stresses are given as the following:

$$\tau_c = \gamma \times d_{MAX} \times S_F \tag{36}$$

$$\tau_p = F_* \times (\gamma_s - \gamma) \times D_{50} \tag{37}$$

Where:

γ_s = Unit weight of the riprap, N/m^3.

Shield's parameter, **F_***, has a default value of 0.047. This is the value used in HEC-11 and changes the basic permissible shear relationship for riprap in HEC-15. The user has the option of overriding the default Shields' parameter. To assist the user in selecting an **F_*** value, the particle shear velocity Reynolds' number is calculated and included in the output.

The Reynolds' number is calculated using equation (38):

$$R_e = \frac{U_* \times D_{50}}{} \tag{38}$$

Where:

U_*	=	Particle shear velocity, m/s.
	=	Kinematic viscosity of water at 15°C.

The Reynolds' number is important in assisting the user in interpreting the hydraulic regime. It has been documented that at high Reynolds' numbers (> 10^5), Shields' parameter significantly increases.[7] At Reynolds' numbers greater than 10^5, HEC-15 suggests an **F_*** value of 0.15. HYCHL defaults to F_* = 0.047 but allows a user to override the default.

In the case of riprap analysis for the channel bottom, the stability factor is calculated as follows:

$$SF_b = \frac{\tau_p}{\tau_c} = \frac{F_* \times (\gamma_s - \gamma) \times D_{50}}{\gamma \times d_{MAX} \times S_F} = \frac{F_* \times (S_g - 1) \times D_{50}}{d_{MAX} \times S_F} \tag{39}$$

Where:

SF_b	=	Stability Factor for the channel bottom.
S_g	=	Specific gravity of the riprap.

Manning's equation can be expressed as:

$$S_F = \frac{V^2 \times n^2}{0.455 \times R_h^{4/3}} \tag{40}$$

Substituting for slope in equation (39), the equation for calculating the stability factor for the channel bottom is given as:

$$SF_b = \frac{F_* \times (S_g - 1) \times D_{50}}{d_{MAX}} \times \frac{0.455 \times R_h^{\frac{4}{3}}}{V^2 \times n^2} \tag{41}$$

For the cases of riprap design of the channel bottom, equation (41) is solved for $\mathbf{D_{50}}$ to give equation (42):

$$D_{50,b} = \frac{SF_b \times d_{MAX} \times V^2 \times n^2}{F_* \times (S_g - 1) \times 0.455 \times R_h^{\frac{4}{3}}} \tag{42}$$

Where:

$D_{50,b}$ = Riprap size for the channel bottom.

<u>Side Shear</u>

The procedure for determining stability factor and riprap size can be extended to the analysis/design of the channel side slopes. The observed shear on the side slopes is calculated as:

$$\tau_c = \gamma \times d_{MAX} \times S_F \times K_{SIDE} \tag{43}$$

where $\mathbf{K_{SIDE}}$ is the ratio of side shear to bottom shear and is obtained in the same manner as described in the Side Shear section for the analysis and design of rigid, vegetative, gabion, and temporary linings. The critical, or permissible, shear is given as:

$$\tau_p = F_* \times (\gamma_s - \gamma) \times D_{50} \times K_2 \tag{44}$$

Where:

$$K_2 = \sqrt{1 - \frac{\sin^2}{\sin^2}} \tag{45}$$

and:

= Angle of side slope.
= Riprap angle of repose.
K_2 = Tractive force ratio.

The angle of repose can be user supplied, or, if it is omitted, a default value is determined as a function of $\mathbf{D_{50}}$ and the type of riprap based on chart 33 of HEC-11. Stability factor for the side slopes is then calculated as the ratio of calculated shear stress to permissible shear stress:

$$SF_{ss} = \frac{F_* \times (\gamma_s - \gamma) \times D_{50} \times K_2}{\gamma \times d_{MAX} \times S_F \times K_{SIDE}} \tag{46}$$

Where:

SF_{ss} = Stability factor for channel side slopes.

Again, applying Manning's equation and substituting for slope, the stability factor for side slopes becomes:

$$SF_{ss} = \frac{F_{*} \times (S_g - 1) \times D_{50} \times K_2}{d_{MAX} \times K_{SIDE}} \times \frac{0.455 \times R_h^{\frac{4}{3}}}{V^2 \times n^2} \tag{47}$$

This equation is similar to the $\mathbf{SF_b}$ equation with the exception of the $\mathbf{K_2/K_{SIDE}}$ term, and reduces to:

$$SF_{ss} = SF_b \times \frac{K_2}{K_{SIDE}} \tag{48}$$

For the case of riprap design of the side slope material, the mean riprap size for the channel side slopes is calculated as,

$$D_{50,ss} = \frac{SF_b \times d_{MAX} \times V^2 \times n^2}{F_{*} \times (S_g - 1) \times 0.455 \times R_h^{\frac{4}{3}}} \times \left[\frac{K_{SIDE}}{K_2}\right] \tag{49}$$

Where:

$D_{50,ss}$ = Stable riprap size for channel side slopes.

Substituting $D_{50,b}$, this equation reduces to:

$$D_{50,ss} = D_{50,b} \times \frac{K_{SIDE}}{K_2} \tag{50}$$

Irregular Channels

HEC-11 discusses design procedures for riprap revetments to be used as channel protection for large streams and rivers while HEC-15 outlines procedures for the design of small roadside channels of constant cross section and slope. HYCHL provides for the analysis or design of both general types of channels. In addition to allowing for the analysis of channels with a specific geometric shape, which are typically small roadside channels, large channel reaches can also be analyzed/designed using the irregular channel shape option.

HYCHL provides for the analysis or design of irregular channels which are lined with riprap. An irregular channel cross section is defined by the user through the input of a series of x-, y-coordinates. The x-coordinates must be in order, left to right, and a maximum of 50 x-, y-coordinates may be used to describe a channel cross section. The y-coordinates must be given as elevation values from any datum. A main channel within the irregular channel must be defined by four x-,y-coordinates or hinge points, as shown in figure 5. The main channel is bounded by points one and four on the left and right sides, and by points two and three on the bottom. From the given four main channel points, side slope z-values and a base width are estimated by connecting these points linearly in a trapezoidal shape. The side shear ratio is determined in the same manner as for a trapezoidal channel shape, which is described in the Side Shear section for the analysis and design of rigid, vegetative, gabion, and temporary linings.

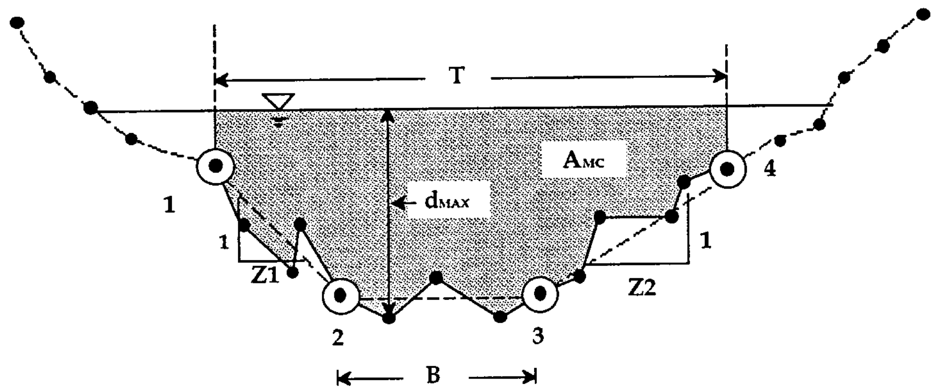


Figure 5. Example of an irregular channel cross section.

Channel area and wetted perimeter are calculated for the area between points 1 and 4. The irregular channel is broken up into a series of rectangular and triangular channel elements. Area and wetted perimeter for each element are calculated and the summation of these values is used in computing the overall hydraulic radius. If the depth, $\mathbf{d_{MAX}}$, exceeds the height bounded by the main channel, then hydraulic calculations for area, wetted perimeter, hydraulic radius, and top width are limited to the area above the main channel ($\mathbf{A_{mc}}$).

Riprap-lined irregular channels can be analyzed for stability given a $\mathbf{D_{50}}$ value or the $\mathbf{D_{50}}$ can be calculated given a stability factor. If the user inputs $\mathbf{S_F}$ and **Q**, and the calculated normal depth, $\mathbf{d_{MAX}}$, exceeds the height of the main channel, an error message results. In this case, a portion of an irregular channel is to be analyzed/designed, and the inputs, **S** and **Q**, must be replaced with $\mathbf{d_{MAX}}$ and velocity, **V**.

<u>Analysis and Design Options</u>

A channel lined with riprap may be analyzed for stability based on a user-supplied riprap size ($\mathbf{D_{50}}$), or a riprap size can be determined by HYCHL given a stability factor (**SF**). The user has the option, based on the provided inputs, to either analyze or design a riprap-lined channel. Stability Factors are calculated for both the channel bottom and side slopes, and if a bend exists, **SF** is calculated for the channel bottom and sides in the bend. For the case of riprap design, $\mathbf{D_{50}}$ is also calculated for both the channel bottom and side slopes in the straight channel reach and in the bend.

There are four input scenarios the user can choose for the analysis or design of a riprap-lined channel. The user must supply either:

1. Slope, Design Flow, D_{50}.
2. Velocity, d_{MAX}, D_{50}.
3. Slope, Design Flow, Stability Factor.
4. Velocity, d_{MAX}, Stability Factor.

The channel will be analyzed for stability given scenarios 1 and 2, and riprap size is designed in scenarios 3 and 4. If only the main channel portion of an irregular channel is to be considered, one of the choices must be either 2 or 4.

USER DOCUMENTATION

Effective use of HYCHL requires an understanding of the interaction between user and the software. While the previous chapter describes the functions of HYCHL, this chapter explains how the user communicates with the software to achieve desired results.

THE INTERACTIVE HYCHL EDITOR

The HYCHL program can be executed through the interactive HYCHL editor (version 6.1) which provides full-screen input and output of data. The user is guided through a series of menus which prompt the user for required inputs for the analysis or design of a channel lining. The HYCHL interactive editor can be accessed either from DOS or from the HYDRAIN system shell.

Executing the HYCHL Interactive Editor

From DOS, execute the interactive editor by changing to the HYCHL directory (typically C:\HYCHL). Type the program name, **CHSHL**, and depress the carriage return (or enter) key (denoted as <Enter>). The interactive menu will appear on the screen. Alternatively, access the HYCHL interactive editor from the HYDRAIN system. To enter HYDRAIN, change to the HYDRAIN directory (typically C:\HYDRAIN), type **HYDRAIN**, and strike <Enter>. A screen will appear showing the member sponsors of the Pooled Fund Project. Another <Enter> reveals a disclaimer message and a third <Enter> will place the user in the Main Menu. Selection of an option within the main menu is done by using the left and right ARROWS to move the cursor to the desired procedure or by striking the highlighted letter of the desired option. From the Main Menu at the Analyze choice, select the HYCHL option. After selecting an input file, HYDRAIN calls CHSHL and the interactive menu will appear. It is a very good idea to add both HYDRAIN and HYCHL directories to the PATH statement in the AUTOEXEC.BAT file.

Using the HYCHL Interactive Editor

When the interactive editor is entered, a screen appears with the following main heading choices: Analyze, Shapes, Lining, Options, and Select. The upper right hand corner (below the HYDRAIN version number) contains information describing the current operations of the editor. The information includes the mode, input file name, and units used in the analysis (English or metric). The information also shows whether the CapsLock, NumLock, and Insert/Replace keys are active. CapsLock is indicated by the capitalization of the mode and units information displayed: all capitals indicates CapsLock is on, initial capitals indicates CapsLock is off. Insert is indicated by "in" or "IN" following units information. Replace is indicated by "rp" or "RP" following units information. NumLock is indicated by presence or absence of "#" following Insert/Replace information. The editor mode can be either guided or edit. The guided mode automatically progresses through the program options and prompts. The guided mode is activated when creating a new file. The edit mode allows changes to information already entered into an existing input data file. The HYCHL input data set typically has a **.CHL** extension. This helps the program to distinguish the input files.

The screen initially appears in the **Shapes** section with the pulldown menu of all channel shape options. A channel shape must be selected regardless of the type of analysis desired. A shape is chosen by using the ARROW keys to highlight the desired channel shape and striking <Enter>, upon which another menu appears prompting the user for inputs specific to the channel shape. Certain input values are checked and must be within certain limits which appear in the short help descriptions. Short helps appear at the bottom of the screen which give descriptions of the highlighted choices. Once the channel shape data are entered, <Enter> returns the editor to the **Shapes** menu and <Esc> places the editor in the main heading choices (**Shapes** is highlighted).

The **Lining** section displays a menu which gives the user three options of lining type analysis, including analyzing a single lining, a composite lining, or all linings. If a single or composite lining is chosen, menus appear which prompt the user to select a lining type(s) and its associated parameters. When all lining data have been input, <Enter> returns the editor to **Lining** menu and <Esc> places the editor in the main heading choices. ***Note: If the user selects to check all linings, no Manning's values should be specified. If any have been entered, they should be removed prior to analysis.***

The **Options** section allows the user to add optional input criteria or to change program defaults in the channel lining analysis. Again, for each option, a menu appears prompting the user for the required data. <Enter> and <Esc> returns the editor to the main heading choices.

The **Select** option allows the user to retrieve, save, or print a file and to temporarily exit to DOS or to Quit. The Quit option terminates the interactive editor and returns to the C:\HYDRAIN prompt. The DOS option allows a temporary exit from the editor to DOS. The interactive editor is reactivated by typing EXIT.

Once all necessary data are supplied by the user, the **Analyze** option must be enacted in order to carry out the analysis. After the **Analysis** parameters are chosen, <Enter> will display a **GO** menu. When <Enter> is struck, analysis is performed by HYCHL using the inputs provided in the interactive editor and numerical and graphical results are displayed. Graphical output assists the user to visualize whether the selected lining is stable or unstable. The user then has the option of viewing the output file for a complete, detailed listing of the results by striking <Enter>, or returning to the interactive editor by striking <Esc>. Upon completion of the run, the output file is automatically assigned an **.LST** filename extension. The file prefix (or node) remains the same as the input file name.

THE COMMAND APPROACH - ORGANIZING THE DATA

HYCHL also functions within the HYDRAIN system through the command language concept. Data entry and data analysis are all dictated by user-supplied commands. A command describes a basic task that HYCHL can recognize. There is only a set number of commands in HYCHL's vocabulary and they must each follow a specific format. A complete list of these commands, along with brief definitions, is shown in table 7. A more detailed description, including format specifications, is included in appendix C. On-line descriptions are also available in the form of long helps (activated by the <F1> key).

Table 7. Glossary of commands.

Command		Description
BEN	-	indicates channel **BEN**d and its radius of curvature.
CHL	-	specifies **CH**anne**L** information such as slope and flow rate.
CPS	-	indicates **C**om**P**o**S**ite channel and its lining transition depth.
END	-	**END**s a command string.
GR	-	cross-section coordinates for an irregular channel.
JOB	-	indicates **JOB** and enters **JOB** title.
LBC	-	indicates **L**ining to be **B**are soil, **C**ohesive.
LBN	-	indicates **L**ining to be **B**are soil, **N**on-cohesive.
LGB	-	indicates **L**ining to be **G**a**B**ion.
LRG	-	indicates **L**ining to be **R**i**G**id.
LRR	-	indicates **L**ining to be **R**ip**R**ap.
LTM	-	indicates **L**ining to be **T**e**M**porary.
LVG	-	indicates **L**ining to be **V**e**G**etative.
N	-	allows input of Ma**N**ning's n-value(s).
NEQ	-	allows for override of Manning's **N EQ**uations.
PAR	-	specifies a **PAR**abolic shaped channel and its associated parameters.
PSS	-	allows input of **P**ermissible **S**hear **S**tress value(s).
REM	-	allows a line for **REM**arks or comments.
SA	-	specifies the main channel boundaries of an irregular channel.
TRP	-	specifies a **TR**a**P**ezoidal shaped channel and its associated parameters.
UNI	-	allows data input/output in metric **UNI**ts.
VRB	-	specifies a **V**-shaped with **R**ounded **B**ottom channel.
VSH	-	specifies a **V-SH**aped channel and its associated parameters.

Commands are the data that a user must specify to describe a system for analysis. These commands may be arranged in almost any order, provided they follow the guidelines provided in the command descriptions. Once these commands are arranged in their final working order, they are collectively referred to as a command string. The command string is what HYCHL needs for analysis.

Figure 6 shows an example command string, broken down into its command name and accompanying data field, with an explanation of each command used. Ordering commands in a HYCHL command string is a relatively easily acquired skill. For instance, using figure 6 as an example, note that the **JOB** command is first. This establishes a labeling header used in the output.

HYCHL Command	Data	Comments
JOB	Command Example	The title of the HYCHL job.
UNI	1	Sets units to metric for both input and output data.
CHL	0.01 1.2	Slope equals 0.01 m/m and flow rate equals 1.2 m^3/s.
CPS	0.2	Lining is composite with lining transition height occurring at 0.2 m from the channel bottom.
LRG	2	Low flow lining is grouted riprap.
LVG	C	Side slope lining is vegetative, class "C".
TRP	1 3	Trapezoidal shape with 1-m base and 3:1 side slopes.
N	0.031 0.040	Manning's roughness value for low flow lining and side slope lining, respectively.
END		Terminates the HYDRO input file

Figure 6. Example of a command string.

Commands operate in "free format" fashion; that is, a space [ ], or a comma [,] are parameter subfield separators that may be used in any amount between each parameter value (spacing between subfields is not critical).

THE HYDRAIN ENVIRONMENT

For those users who have obtained HYCHL as part of the FHWA's HYDRAIN package, consult the HYDRAIN documentation for information on how to use the software system.

The interactive editor allows the user to input data with more visual interaction than the HYDRAIN editor. It is accessible through the HYDRAIN system or directly from DOS. Its operation was described earlier.

There are four methods by which HYCHL can be run. Three of these are within the HYDRAIN environment. The first method is to run HYCHL from the HYDRAIN editor. This allows the user the option of immediate review, editing capabilities. As discussed earlier, the second and third methods execute HYCHL from the interactive editor. The final method executes HYCHL from the DOS prompt. Further discussion of these options is in the HYDRAIN documentation.

APPENDIX A: BENCHMARK EXAMPLES

The following examples are hypothetical systems modeled by HYCHL which are provided to illustrate some of the program's capabilities. It should be recognized that these examples are not meant to give a comprehensive guide of every command option. The user is referred to appendix C for this information. It is intended that these examples will achieve at least these four objectives:

1. Provide guidance for creating command strings.
2. Demonstrate uses for many of the commands.
3. Provide information on how to set up a problem.
4. Demonstrate what to expect for output.

The examples offered here collectively make use of most of the available commands. Some examples include a figure to schematically represent a given problem. Each example provides the input data set for the run and its corresponding output. Each of the six examples provides a different type of HYCHL application. The applications are:

1. Designing temporary and permanent linings.
2. Analyzing a composite lining.
3. Designing rock riprap lining.
4. Analyzing rock riprap in a bend.
5. Analyzing a gabion lining.
6. Designing an irregular channel lining.

Example One: Designing Temporary and Permanent Linings

Problem:

This example shows a procedure for designing a temporary lining with a permanent grass cover. A roadside channel, with 0.015 m/m slope, is planned to carry 1.2 m^3/s on a temporary lining. A permanent vegetative lining must be designed to replace the temporary lining and carry 2.3 m^3/s. To solve the problem, the designer must first choose a channel geometry that will apply to both the temporary and permanent linings. The example uses the **PAR** command which is a parabolic shape with 5.2 m maximum top width, and 1.7 m maximum depth. The **CHL** command shows a slope of 0.015 m/m and the design flow rate for the temporary lining. By not specifying a lining type, all temporary and permanent flexible linings are analyzed.

Input File: HYCHL1.CHL

```
JOB Example One:  Designing Temporary & Permanent Linings
UNI 1
CHL 0.015  1.2
PAR 5.2  1.7
END
```

Discussion of output:

Interpreting the output allows selection of both the temporary and permanent lining. HYCHL yields three stable temporary linings: straw with net, curled wood mat, and synthetic mat. Examination of the MAX Q column also shows that only one permanent lining (vegetative Class A) will be stable when the flow is 2.3 m^3/s.

Output: HYCHL1.LST

```
          ******  HYCHL  ****** (Version 6.1) ******           Date 10-15-97

 Commands Read From File: hychl1.chl


       JOB EXAMPLE ONE:  DESIGNING TEMPORARY & PERMANENT LININGS
       UNI 1
 ** UNITS PARAMETER = 1  (METRIC)
       CHL 0.015  1.2
       PAR 5.2  1.7
 ** MAX TOP WIDTH (m)    5.200   MAX DEPTH (m)    1.700
       END
```

```
***************END OF COMMAND FILE************

 EXAMPLE ONE:  DESIGNING TEMPORARY & PERMANENT LININGS
 ------------
 INPUT REVIEW
 ------------
   DESIGN PARAMETERS:
       DESIGN DISCHARGE (m^3/s):            1.200
       CHANNEL SHAPE:                   PARABOLIC
       CHANNEL SLOPE (m/m):                  .015

 -------
 RESULTS
 -------
                SHEAR STRESS (Pa) Len of Super                      ---DESIGN--
                 --------------- Protect Elev        Stab.   Max Q  Depth  Mann
 Lining Type      Permiss  Bottom   (m)   (mm) Remark Factor (m^3/s)  (m)    n
 ---------------- ------- ------- ------ ----- ------ ------ ------- ------ ----
     TEMPORARY (FLEXIBLE)

 WOVEN PAPER NET      7.2   41.9    .000     0 UNSTAB    .17    .024   .285 .013
 JUTE NET            21.5   53.5    .000     0 UNSTAB    .40    .143   .364 .022
 FIBERGLASS SINGLE   28.7   53.1    .000     0 UNSTAB    .54    .292   .361 .022
 FIBERGLASS DOUBLE   40.7   54.5    .000     0 UNSTAB    .75    .614   .371 .023
 STRAW WITH NET      69.4   65.1    .000     0 STABLE   1.07   1.397   .443 .034
 CURLED WOOD MAT     74.2   66.8    .000     0 STABLE   1.11   1.538   .454 .036
 SYNTHETIC MAT       95.8   57.1    .000     0 STABLE   1.68   3.882   .389 .026

     PERMANENT (FLEXIBLE)

 VEGETATIVE  A      177.2  128.6    .000     0 STABLE   1.38   3.235   .874 .143
 VEGETATIVE  B      100.5  101.2    .000     0 UNSTAB    .99   1.176   .689 .086
 VEGETATIVE  C       47.9   84.5    .000     0 UNSTAB    .57    .245   .575 .059
 VEGETATIVE  D       28.7   77.3    .000     0 UNSTAB    .37    .076   .526 .049
 VEGETATIVE  E       16.8   72.9    .000     0 UNSTAB    .23    .017   .496 .043

     RIGID

 CONCRETE         *******   41.5    .000     0 STABLE ******    .000   .282 .013
 GROUTED RIPRAP   *******   61.5    .000     0 STABLE ******    .000   .418 .030
 STONE MASONRY    *******   63.4    .000     0 STABLE ******    .000   .431 .032
 SOIL CEMENT      *******   53.1    .000     0 STABLE ******    .000   .361 .022
 ASPHALT          *******   45.8    .000     0 STABLE ******    .000   .311 .016

 SOME RIPRAP AND GABION LININGS MAY ALSO BE STABLE
 *** NORMAL END OF HYCHL ***
```

Example Two: Analyzing Composite Linings

Problem:

This example shows how to analyze a compositely lined channel. It is similar to example 13 of HEC-15. A trapezoidal channel on a 0.02 m/m slope has a 0.91-m base width and 3:1 (horizontal:vertical) side slopes. The flow is 0.28 m^3/s, the low-flow lining is concrete, and the side flow lining is vegetative (Class C). The lining transition depth is zero m, meaning the low flow lining only lines the channel bottom.

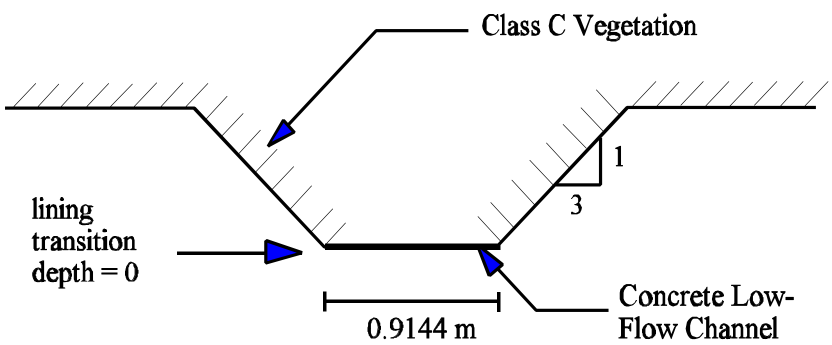


Figure 7. Composite lining example.

Input File: HYCHL2.CHL

```
JOB Example Two: Analyzing Composite Linings
UNI 1
CHL 0.02  0.28
TRP 0.91  3
LRG 1 0.30
CPS 0
LVG C
END
```

Discussion of output:

The output shows that both linings are stable with the vegetative lining having a safety factor of 1.11. It is almost flowing with maximum discharge, which is 0.34 m^3/s. The depth is 265 mm and the effective Manning's **n** value is 0.071. The final line shows that $\mathbf{K_{SU}}$–the ratio of side lining shear to bottom lining shear–is 0.86.

Output File: HYCHL2.LST

```
          ******  HYCHL  ****** (Version 6.1) ******           Date 10-15-97

 Commands Read From File: hychl2.chl


       JOB EXAMPLE TWO: ANALYZING COMPOSITE LININGS
       UNI 1
 ** UNITS PARAMETER = 1  (METRIC)
       CHL 0.02  0.28
       TRP 0.91  3
 ** LEFT SIDE SLOPE    3.0 AND RIGHT SIDE SLOPE    3.0
 ** THE BASE WIDTH OF THE TRAPEZOID (m)     .910
       LRG 1 0.30
 ** THE MAXIMUM CHANNEL DEPTH (m) IS     .300
       CPS 0
       LVG C
       END
***************END OF COMMAND FILE************
```

```
EXAMPLE TWO: ANALYZING COMPOSITE LININGS
------------
INPUT REVIEW
------------
  DESIGN PARAMETERS:
      DESIGN DISCHARGE (m^3/s):             .280
      CHANNEL SHAPE:                   TRAPEZOIDAL
      CHANNEL SLOPE (m/m):                  .020
      LINING TRANSITION HEIGHT (m):       .000
-----------------------------------------
HYDRAULIC CALCULATIONS USING NORMAL DEPTH
-----------------------------------------

                         DESIGN     MAXIMUM
                         ------     -------
FLOW (m^3/s)               .280        .338
DEPTH (m)                  .264        .284
AREA (m^2)                 .449        .500
WETTED PERIMETER (m)      2.579       2.704
HYDRAULIC RADIUS (m)       .174        .185
VELOCITY (m/s)             .624        .677
MANNINGS N (LOW FLOW)      .013        .013
MANNINGS N (SIDE SLOPE)    .093        .087
EFFECTIVE MANNINGS N       .071        .068

------------------
STABILITY ANALYSIS
------------------

                      LINING       PERMIS SHR   CALC. SHR  STAB.
    CONDITION         TYPE          ( Pa )       ( Pa )    FACTOR   REMARKS
    ---------         ---------    ----------   ---------  ------   -------
LOW FLOW LINING
  BOTTOM; STRAIGHT   CONCRETE         *******     51.73    ******   STABLE
SIDE SLOPE LINING
  SIDE; STRAIGHT     VEGETATIVE  C      47.88     44.54      1.07   STABLE

RATIO OF SIDE SHEAR TO BOTTOM SHEAR =      .86

*** NORMAL END OF HYCHL ***
```

Example Three: Designing Rock Riprap Linings

Problem:

A riprap-lined trapezoidal channel is to be designed which can convey a design discharge of 2.5 m^3/s on a slope of 0.03 m/m. A stability factor of 1.2 is prescribed by the user in the **LRR** command.

Input File: HYCHL3.CHL

```
JOB Example Three: Designing Rock Riprap Linings
UNI 1
CHL 0.03  2.5
TRP 1.8  3
LRR -1.2 2
END
```

Discussion of Output:

The Bathurst hydraulic procedure was enacted in this run due to rock protrusion, i.e., the value of $\mathbf{d_a}$ / $\mathbf{D_{50}}$ was less than 2. Maximum discharge is not computed for the channel and does not appear in the hydraulic calculations. In the riprap design section, a $\mathbf{D_{50}}$ value is given for both the bottom and sides of the channel.

Output File: HYCHL3.LST

```
          ******  HYCHL  ****** (Version 6.1) ******           Date 10-15-97

 Commands Read From File: hychl3.chl


       JOB EXAMPLE THREE: DESIGNING ROCK RIPRAP LININGS
       UNI 1
 ** UNITS PARAMETER = 1  (METRIC)
       CHL 0.03  2.5
       TRP 1.8  3
 ** LEFT SIDE SLOPE    3.0 AND RIGHT SIDE SLOPE    3.0
 ** THE BASE WIDTH OF THE TRAPEZOID (m)    1.800
       LRR -1.2 2
 ** STABILITY FACTOR    1.20
       END
***************END OF COMMAND FILE************

 EXAMPLE THREE: DESIGNING ROCK RIPRAP LININGS
 ------------
 INPUT REVIEW
 ------------
   DESIGN PARAMETERS:
       DESIGN DISCHARGE (m^3/s):           2.500
       CHANNEL SHAPE:                  TRAPEZOIDAL
       CHANNEL SLOPE (m/m):                 .030
 -------------------------------------
 HYDRAULIC CALCULATIONS USING BATHURST
 -------------------------------------

 FLOW (m^3/s)              2.500
```

```
MAX DEPTH (m)              .508
AREA (m^2)                1.680
WETTED PERIMETER (m)      5.001
HYDRAULIC RADIUS (m)       .336
AVG VELOCITY (m/s)        1.489
MANNINGS EQUIVALENT        .058
Davg / D50                 1.48
FROUDE NUMBER               .67
REYNOLDS NUMBER (10^5)      .86
-------------
RIPRAP DESIGN
-------------

                      LINING    PERMIS SHR   CALC. SHR  STAB.
    CONDITION         TYPE       ( Pa )       ( Pa )    FACTOR   D50(m)
    ---------          ------    ----------   ---------  ------   -------
  BOTTOM; STRAIGHT   RIPRAP         177.86     149.26      1.20     .234
  SIDE; STRAIGHT     RIPRAP         152.92     128.32      1.20     .229

*** NORMAL END OF HYCHL ***
```

Example Four: Rock Riprap Analysis in a Bend

Problem:

This example illustrates the rock riprap analysis procedure in a bend. A trapezoidal channel is to carry a design flow of 0.91 m^3/s on a longitudinal slope of m/m. The user-supplied riprap size is 0.08 m. The channel is to have a bend with a radius of curvature of 18.3 m. The trapezoidal channel section has a base width of 3.1 m and unequal side slopes (2.7 to 1 and 3 to 1, horizontal to vertical).

Input File: HYCHL4.CHL

```
JOB Example Four: Analysis of Rock Riprap in a Bend
UNI 1
BEN 18.3
CHL 0.01  0.91
TRP 3.1 2.7 3
LRR 0.08
END
```

Discussion of Output:

Input parameters are echoed in the first section of output and the hydraulic calculations follow. Reynolds' number is included in the hydraulic calculations to assist the user in determining a value for Shields' parameter (0.047 is the default). Maximum discharge is computed but it is applicable only to the straight channel section. The stability analysis includes stability factor calculations for both the bottom and sides of the straight channel section and the bend. The given riprap size was determined to be stable (SF > 1.0) for all channel areas.

Output File: HYCHL4.LST

```
          ******  HYCHL  ****** (Version 6.1) ******           Date 10-15-97

 Commands Read From File: hychl4.chl


       JOB EXAMPLE FOUR: ANALYSIS OF ROCK RIPRAP IN A BEND
       UNI 1
 ** UNITS PARAMETER = 1  (METRIC)
       BEN 18.3
       CHL 0.01  0.91
       TRP 3.1 2.7 3
 ** LEFT SIDE SLOPE    2.7 AND RIGHT SIDE SLOPE    3.0
 ** THE BASE WIDTH OF THE TRAPEZOID (m)    3.100
       LRR 0.08
 ** D50 (m)    .080
       END
***************END OF COMMAND FILE************
```

```
EXAMPLE FOUR: ANALYSIS OF ROCK RIPRAP IN A BEND
------------
INPUT REVIEW
------------
  DEFAULT ANGLE OF REPOSE (degrees):     40.70
  DESIGN PARAMETERS:
      DESIGN DISCHARGE (m^3/s):            .910
      CHANNEL SHAPE:                 TRAPEZOIDAL
      CHANNEL SLOPE (m/m):                 .010
      RADIUS OF CURV. FOR BEND (m):    18.301
-----------------------------------------
HYDRAULIC CALCULATIONS USING NORMAL DEPTH
-----------------------------------------

                                        MAXIMUM
                         DESIGN    (NO BEND)
                         ------     -------
FLOW (m^3/s)               .910       2.730
DEPTH (m)                  .307        .525
AREA (m^2)                1.219       2.414
WETTED PERIMETER (m)      4.953       6.272
HYDRAULIC RADIUS (m)       .246        .385
VELOCITY (m/s)             .746       1.131
MANNINGS N (LOW FLOW)      .053        .047
REYNOLDS NUMBER (10^5)      .17

------------------
STABILITY ANALYSIS
------------------

                      LINING    PERMIS SHR   CALC. SHR  STAB.
    CONDITION         TYPE      ( Pa )        ( Pa )     FACTOR   REMARKS
    ---------          ------    ----------    ---------  ------   -------
  BOTTOM; STRAIGHT   RIPRAP          60.81     30.07       2.02   STABLE
  BOTTOM; BEND       RIPRAP          60.81     42.73       1.42   STABLE
  SIDE; STRAIGHT     RIPRAP          51.47     25.56       2.01   STABLE
  SIDE; BEND         RIPRAP          51.47     36.32       1.42   STABLE

       SUPER ELEVATION (m)          .015
       LENGTH OF PROTECTION (m)    5.165

RATIO OF SHEAR IN BEND TO SHEAR IN STRAIGHT CHANNEL =    1.42

*** NORMAL END OF HYCHL ***
```

Example Five: Gabion Lining Analysis

Problem:

The example shows the analysis of a gabion-lined channel. The gabion lining command (**LGB**) indicates a gabion lining with a riprap size of 0.08 m and a mattress thickness of 0.16 m. The slope is 0.05 m/m (0.05 ft/ft) and the trapezoid has a base width of 1.3 m. The flow rate is 0.5 m^3/s.

Input File: HYCHL5.CHL

```
JOB Example Five: Gabion Lining Analysis
UNI 1
CHL 0.05   0.5
TRP 1.3  2.7  3
LGB 0.08  0.16
END
```

Discussion of Output:

The output shows the normal depth computation results and the maximum discharge. Since the calculated shear stress is less than the permissible shear stress of the gabion mattress, the channel lining is stable.

Output File: HYCHL5.LST

```
          ******  HYCHL  ****** (Version 6.1) ******           Date 10-15-97

 Commands Read From File: hychl5.chl


       JOB EXAMPLE FIVE: GABION LINING ANALYSIS
       UNI 1
 ** UNITS PARAMETER = 1  (METRIC)
       CHL 0.05   0.5
       TRP 1.3  2.7  3
 ** LEFT SIDE SLOPE    2.7 AND RIGHT SIDE SLOPE    3.0
 ** THE BASE WIDTH OF THE TRAPEZOID (m)    1.300
       LGB 0.08  0.16
 ** MEAN STONE SIZE (m)       .080
 ** MATTRESS THICKNESS (m)    .160
 ** SPECIFIC GRAVITY EQUALS   2.65
       END
***************END OF COMMAND FILE************
```

```
EXAMPLE FIVE: GABION LINING ANALYSIS
------------
INPUT REVIEW
------------
  DEFAULT ANGLE OF REPOSE (degrees):     37.20
  DESIGN PARAMETERS:
      DESIGN DISCHARGE (m^3/s):            .500
      CHANNEL SHAPE:                  TRAPEZOIDAL
      CHANNEL SLOPE (m/m):                 .050
-----------------------------------------
HYDRAULIC CALCULATIONS USING NORMAL DEPTH
-----------------------------------------

                         DESIGN     MAXIMUM
                         ------     -------
FLOW (m^3/s)               .500       1.899
DEPTH (m)                  .229        .416
AREA (m^2)                 .447       1.036
WETTED PERIMETER (m)      2.683       3.815
HYDRAULIC RADIUS (m)       .167        .271
VELOCITY (m/s)            1.119       1.834
MANNINGS N (LOW FLOW)      .060        .051

------------------
STABILITY ANALYSIS
------------------

                      LINING       PERMIS SHR   CALC. SHR  STAB.
    CONDITION         TYPE         ( Pa )       ( Pa )     FACTOR   REMARKS
    ---------         ---------    ----------   ---------  ------   -------
LOW FLOW LINING
  BOTTOM; STRAIGHT   GABION            204.05    112.15      1.82   STABLE

*** NORMAL END OF HYCHL ***
```

Example Six: Irregular Channel Lining Design

Problem:

This example illustrates the design of a riprap-lined channel for an irregular cross section. Figure 8 shows a sketch of the cross section detailing the main channel and the left and right floodplains. Inputs include a field measured maximum depth of 3.8 m and a main channel velocity of 2.1 m/s. The design incorporates a stability factor of 1.2.

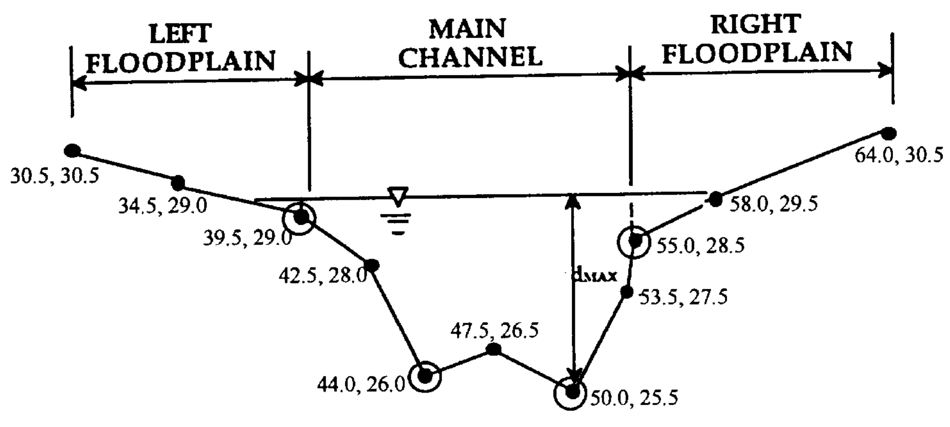


Figure 8. Irregular channel example.

Input File: HYCHL6.CHL

```
JOB Example Six: Riprap Lined Irregularly Shaped Channel
UNI 1
CHL -3.8  -2.1
GR  30.5,30.5 34.5,29.0 39.5,29.0 42.5,28.0 44.0,26.0 47.5,26.5 50.0,25.5
    53.5,27.5 55.0,28.5 58.0,29.0 64.0,30.5
SA  39.5  44.0  50.0  55.0
LRR -1.2 2
END
```

Discussion of Output:

The x-, y-coordinates describing the cross section are printed along with the x-value of the four coordinates which bound the main channel. Due to a high Reynolds' number, HYCHL has provided a message so that the user can consider increasing Shields' parameter. In the riprap design section, $\mathbf{D_{50}}$ was sized for both the channel bottom and the channel side slope for a stability factor of 1.2.

Output File: HYCHL6.LST

```
          ******  HYCHL  ****** (Version 6.1) ******           Date 10-15-97

 Commands Read From File: hychl6.chl


       JOB EXAMPLE SIX: RIPRAP LINED IRREGULARLY SHAPED CHANNEL
       UNI 1
 ** UNITS PARAMETER = 1  (METRIC)
       CHL -3.8  -2.1
       GR  30.5,30.5 34.5,29.0 39.5,29.0 42.5,28.0 44.0,26.0 47.5,26.5
50.0,25.5
 ** NUMBER  X-COORD( m)  Y-COORD( m)
 **    1        30.500       30.500
 **    2        34.500       29.000
 **    3        39.500       29.000
 **    4        42.500       28.000
 **    5        44.000       26.000
 **    6        47.500       26.500
 **    7        50.000       25.500
 **    8        53.500       27.500
 **    9        55.000       28.500
 **   10        58.000       29.000
 **   11        64.000       30.500
       SA  39.5  44.0  50.0  55.0
 **   LOCATION    X COORD ( m)
 **  LEFT BANK        39.500
 **  LEFT BASE        44.000
 **  RIGHT BASE       50.000
 **  RIGHT BANK       55.000
       LRR -1.2 2
 ** STABILITY FACTOR    1.20
       END
***************END OF COMMAND FILE************
```

```
EXAMPLE SIX: RIPRAP LINED IRREGULARLY SHAPED CHANNEL
------------
INPUT REVIEW
------------
  IRREGULAR CHANNEL CALCULATIONS:
      LEFT SIDE SLOPE EQUIVALENT:         1.5
      RIGHT SIDE SLOPE EQUIVALENT:        1.7
      BASE WIDTH EQUIVALENT (m):          6.000
  DESIGN PARAMETERS:
      DESIGN VELOCITY (m/s):             2.100
      CHANNEL SHAPE:                  IRREGULAR
      CHANNEL SLOPE (m/m):                 .000
      MAXIMUM FLOW DEPTH (m):            3.800
----------------------------------------------------------
HYDRAULIC CALCULATIONS USING NORMAL DEPTH FOR MAIN CHANNEL
----------------------------------------------------------

                         DESIGN
                         ------
FLOW (m^3/s)             76.714
MAX DEPTH (m)             3.800
AREA (m^2)               36.539
WETTED PERIMETER (m)     17.725
HYDRAULIC RADIUS (m)      2.061
AVG VELOCITY (m/s)        2.100
MANNINGS N (LOW FLOW)      .052
Davg / D50                 8.94
EQUIVALENT SLOPE (m/m)     .005
REYNOLDS NUMBER (10^5)     1.03
*** WARNING *** REYNOLDS NUMBER IS LARGER THAN 10^5

-------------
RIPRAP DESIGN
-------------

                      LINING    PERMIS SHR   CALC. SHR  STAB.
    CONDITION         TYPE       ( Pa )       ( Pa )    FACTOR   D50(m)
    ---------          ------    ----------   ---------  ------   -------
  BOTTOM; STRAIGHT   RIPRAP         200.27    168.51      1.20     .263
  SIDE; STRAIGHT     RIPRAP         133.73    112.52      1.20     .319

*** NORMAL END OF HYCHL ***
```

APPENDIX B: FOOTPRINTS FOR TYPICAL APPLICATIONS

This section presents two basic HYCHL applications represented by an arrangement of command strings. These command strings, or footprints, are depicted in this section for the following typical applications:

1. Riprap channel design.
2. Analysis of a non-riprap channel.

These two footprints are contained in files on the HYDRAIN diskettes. These files are comprised of command lines with empty data fields for which the user may supply the appropriate data (footprint files should be copied and renamed before any editing is done).

1. Riprap Channel Design

Filename: RRCH˜FP.CHL

HYCHL determines the stability factor given the flow and slope (or depth and velocity) and mean particle diameter, D_{50}. Another function of HYCHL is to determine the mean particle diameter given the flow and slope (or velocity and depth) and stability factor. The typical footprint of this application is as follows:

```
rem--->Riprap Channel Design
rem--->REMOVE all unused command lines (Alt + D)
rem--->REQUIRED first command, JOB
JOB
CHL
LRR
rem--->Cross section geometry---Select <TRP>, <PAR>, <VRB>, <VSH>, or <GR and
rem--->SA>:
TRP
PAR
VRB
VSH
GR
SA
rem--->OPTIONAL:  BEN, N, and PSS commands
BEN
N
PSS
END
```

2. Analysis of Non-riprap Channel

Filename: ANCHL˜FP.CHL

HYCHL determines the maximum flow in a channel given the cross section geometry and channel slope. The typical footprint of this application is as follows:

```
rem--->Analysis of Non-riprap Channel
rem--->REMOVE all unused command lines (Alt + D)
rem--->REQUIRED first command, JOB
JOB
rem--->Command UNI, if used, must be the first active command
UNI 1
CHL
rem--->Channel lining types---<LBC>, <LBN>, <LGB>, <LRG>, <LTM>, or <LVG>
LBC
LBN
LGB
LRG
LTM
LVG
rem--->Cross section geometry---<PAR>, <TRP>, <VRB>, or <VSH>
PAR
TRP
VRB
VSH
rem--->OPTIONAL---BEN, N, and PSS commands
BEN
N
PSS
END
```

APPENDIX C: HYCHL COMMANDS

This appendix details the meaning and syntax of each command available in HYCHL. The descriptions are ordered alphabetically and include information on the command name, its purpose, and its structure. It also includes important notes pertaining to the command. Those commands designated as "required" must be included in any run.

COMMAND BEN - BENd information

Purpose: To analyze a channel BENd.

Structure:

BEN Rc

Rc - radius of curvature, m

Note: The channel radius of curvature is measured to the middle of the channel.

COMMAND CHL - CHanneL information (required)

Purpose: To specify design or analysis conditions.

Structure: (2 options)

CHL slope (, qd, qlin)

-- OR --

CHL -dmax, -v, (, qlin)

1) slope - Slope of channel, ft/ft (m/m)
2) qd - OPTIONAL - Design discharge, (optional), ft^3/s (m^3)
3) qlin - OPTIONAL - Lateral flow contribution, $ft^3/s/ft$ (m^3/m)

-- OR --

1) -dmax - maximum depth of flow in main channel, m, expressed as a negative number to distinguish it from "slope".
2) -v - average velocity of flow in main channel, ft/s, (m/s), expressed as a negative number to distinguish it from "slope".
3) qlin - OPTIONAL - Lateral flow contribution, $ft^3/s/ft$ (m^3/m)

Notes:

1) For a riprap-lined channel, the user may supply maximum depth, dmax, and average velocity, v rather than slope and design discharge. If a portion of an irregular riprap-lined channel is to be analyzed, dmax and v must be input. Both dmax and v values are preceded by a minus sign to distinguish them from slope and qd.

2) If the qd or -v parameter is left blank or a zero is input, then the program calculates the maximum discharge for the channel but does not evaluate stability.

COMMAND CPS - ComPoSite lining information

Purpose: To analyze a compositely-lined channel.

Structure:

CPS htl

htl - Lining transition depth, m

Notes:

1) The lining transition height is measured from the channel bottom to the point of transition from low flow lining to side slope lining.

2) If this command is used, two lining cards must be specified, one for the low flow lining and one for the side slope lining.

COMMAND END - END of run (required)

Purpose: To signal the end of the command string.

Structure:

END (no fields)

Note: An END command must be present and must be the last command.

COMMAND GR - cross section GRound geometry

Purpose: To specify x-, y-coordinates that define cross section geometry.

Structure:

GR x(1), y(1), x(2), y(2),..., x(n), y(n)

nx)	x(i)	-	x-coordinate, from an arbitrary horizontal datum, the ith ground point, m
ny)	y(i)	-	y-coordinate, above common elevation datum of the ith ground point, m

Notes:

1) The parenthetical notation is for illustration purposes only.

2) The maximum number of x-, -y coordinates is 50.

3) x-, y-coordinates are oriented from left bank to right bank looking upstream (n is the total number of coordinates).

COMMAND JOB - JOB start (required)

Purpose: To initiate a job and specify a job title.

Structure:

JOB jobtitle

jobtitle - (optional) alphanumeric characters describing the job

Note: JOB must be the first command. Only one JOB command per command string is permitted. Only 15 characters describing the job are permitted in data sets intended for use with the interactive graphics shell. Longer strings cause an error.

COMMAND LBC - Lining Bare soil, Cohesive

Purpose: To analyze a channel lined with cohesive bare soil.

Structure

LBC PI, Looseness

1) PI - Plasticity index, dimensionless
2) looseness - OPTIONAL - measure of cohesiveness; 1 = "loose," 2 = "medium" (default), 3 = "compact"

Notes:

1) The plasticity index value is a measure of the cohesiveness of the soil and must have a value greater than 3 and less than 50.

2) The soil "looseness" can be one of three values:

   1 - "loose" - soil is loose in consistency.
   2 - "medium" - soil has a medium consistency.
   3 - "compact" - soil is dense or compact.

3) The default looseness value is "medium."

COMMAND LBN - Lining Bare soil, Non-cohesive

Purpose: To analyze a channel lined with non-cohesive soil.

Structure:

LBN D_{50}

D_{50} - mean particle size of the soil, m

COMMAND LGB - Lining GaBion

Purpose: To analyze a gabion lined channel.

Structure:

LGB D_{50}, mt (, spgrav)

1) D_{50} - Mean gabion rock diameter, m
2) mt - Gabion mattress thickness, m
3) spgrav - OPTIONAL - Specify gravity (default = 2.65).

COMMAND LRG - Lining RiGid information

Purpose: To analyze a channel with a rigid lining.

Structure:

LRG num, dmx

1) num - rigid lining type number:
   - 1 - concrete.
   - 2 - grouted riprap.
   - 3 - stone masonry.
   - 4 - soil cement.
   - 5 - asphalt.
2) dmx - maximum channel depth, m

Note: Since permissible shear of rigid linings is considered to be infinite, dmx acts as a limitation on depth of flow for the calculation of maximum discharge.

COMMAND LRR - Lining RipRap

Purpose: To specify the analysis of a riprap lined channel.

Structure: (2 options)

LRR D50, type (, angrep, spgrav, shields)

-- OR --

LRR -sf, type (, angrep, spgrav, shields)

1) D_{50} - Mean riprap diameter, m

-- OR --

1) -(sf) - Stability factor

2) type - Number corresponding to riprap type:
1 - crushed rock.
2 - very angular (default).
3 - very rounded.

3) angrep - OPTIONAL - Angle of repose, degrees

4) spgrav - OPTIONAL - Specific gravity of riprap (default = 2.65)

5) shields - OPTIONAL - Shields' parameter, F_* (default = 0.047)

Notes:

1) D_{50} is input if stability analysis is required for a given riprap size. Stability factor is input if a riprap design procedure is to be performed. sf is preceded by a minus sign to distinguish it from D_{50}.

2) The parameter angrep is optional and should only be entered as an override variable. If angrep is left blank or a zero is entered, the program calculates this value based on type and D_{50} (chart 12 in HEC-15).

3) The user may override Shields' parameter at any time but for Reynolds' number greater than 10^5, the user may want to choose 0.15 as Shields' number (p. 87 of HEC-15).

COMMAND LTM - Lining TeMporary information

Purpose: To analyze a channel with a temporary lining type.

Structure:

LTM num

num - number corresponding to the temporary lining type:

1 - woven paper net.
2 - jute net.
3 - fiberglass single.
4 - fiberglass double.
5 - straw with net.
6 - curled wood mat.
7 - synthetic mat.

COMMAND LVG - Lining VeGetative

Purpose: To analyze a vegetative lined channel.

Structure:

LVG class

class - Retardance class of the vegetation. There are 5 classes of vegetation with varying degrees of grass height and thickness:

A - Vegetation Class A, which is the tallest in height.
B - Vegetation Class B, which is tall in height.
C - Vegetation Class C, which is medium in height.
D - Vegetation Class D, which is short in height.
E - Vegetation Class E, which is shortest in height.

COMMAND N - optional user-supplied value for Manning's **N**

Purpose: To allow user to override default Manning's **N**.

Structure:

N n(1), n(2)

1) n(1) - Manning's **N** value for low flow lining
2) n(2) - Manning's **N** value for side slope lining

Notes:

1) The side slope lining Manning's **N** value, n(2) is omitted if the lining is not composite.

2) When using the interactive graphics shell, this command should not be used when all linings are to be checked. Any values for **N** should be removed prior to analysis.

3) If this command is used, **NEQ** cannot be used.

COMMAND NEQ - optional override of equations for Manning's **N**

Purpose: To allow user to employ the Anderson or Blodgett equations for Manning's **N**.

Structure:

NEQ select

select - override selection (1 = Anderson, 2 = Blodgett)

Notes:

1) Command is only valid for riprap or gabion linings.

2) If this command is used, **N** cannot be used.

COMMAND PAR - PARabolic channel information

Purpose: Specifies a parabolic channel shape for analysis.

Structure

PAR tm, dm

1)	tm	-	Maximum top width of the channel, m
2)	dm	-	Maximum depth corresponding to the maximum top width, m

Note: Both parameters, tm and dm, are used to define the parabola. Any channel width along with its corresponding depth may be entered instead of the widths and depths at the maximum.

COMMAND PSS - Permissible Shear Stress

Purpose: To allow the user the option of overriding the default shear value.

Structure:

PSS tp(1), tp(2)

1)	tp(1)	-	Permissible shear stress value for low flow lining, N/m^2
2)	tp(2)	-	Permissible shear stress value for side slope lining, N/m^2

Note: The side slope shear stress value, tp(2) is omitted if the lining is not composite.

COMMAND REM - REMark

Purpose: To provide remarks or comments.

Structure:

REM (any alphanumeric characters).

COMMAND SA - SubAreal hinge points

Purpose: To specify main channel boundaries of an irregular channel.

Structure:

SA x_{lc}, x_{lb}, x_{rb}, x_{rc}

1) x_{lc} - x-coordinate of the left bank of a main channel, m
2) x_{lb} - x-coordinate of the left base of a main channel, m
3) x_{rb} - x-coordinate of the right base of a main channel, m
4) x_{rc} - x-coordinate of the right bank of a main channel, m

Notes:

1) This command must be used for irregular channels.

2) The x-values have the same arbitrary horizontal datum as the irregular channel.

3) The x-values must be in ascending order left to right, looking upstream, and must be in the same range as the x-coordinates for the irregular channel.

COMMAND TRP - TRaPezoidal channel shape

Purpose: Specifies a trapezoidal channel shape for analysis.

Structure:

TRP b, z1 (, z2)

1) b - Bottom width of the channel, m
2) z1 - Left side slope, horizontal:vertical (z1:1)
3) z2 - OPTIONAL - Right side slope, horizontal:vertical (z2:1) if different from left slope.

Note: If a right side slope value, z2, is not entered, the program sets the left and right side slopes equal to z1.

COMMAND UNI - UNIt conversion

Purpose: To allow data input in metric units.

Structure:

UNI units

units - 0 = English system of units (default)
1 = metric system of units

Note: This command is optional if the English system of units is desired.

COMMAND VRB - V-shaped with Rounded Bottom channel shape

Purpose: Specifies a V-shaped with rounded bottom channel for analysis.

Structure:

VRB z1

z1 - Left and right side slope, horizontal:vertical (1)

Note: By definition, the left and right side slopes must be equal for a V-shaped with rounded bottom channel.

COMMAND VSH - V-SHape channel information

Purpose: Specifies a V-shaped channel for analysis.

Structure:

VSH z1, z2

1) z1 - Left side slope, horizontal:vertical (1)
2) z2 - Right side slope, horizontal:vertical (1)

Note: If the right side slope value, z2, is not entered, the program sets the left and right side slopes equal to z1.

REFERENCES

1) Federal Highway Administration, "Design of Roadside Channels with Flexible Linings," Hydraulic Engineering Circular Number 15, FHWA-IP-87-7, April 1988.

2) Federal Highway Administration, "Design of Riprap Revetment," Hydraulic Engineering Circular Number 11, FHWA-IP-89-016, March 1989.

3) Daryl B. Simons, Yung Hai Chen, and Lawrence J. Swenson, "Hydraulic Test to Develop Design Criteria for the Use of Reno Mattresses," prepared by Simons, Li, and Associates for Maccaferri Steel Wire Products, LTD, 1983.

4) J.C. Blodgett, "Rock Riprap Design for Protection of Stream Channels Near Highway Structures: Volume 1 - Hydraulic Characteristics of Open Channels," USGS Water-Resources Investigations Report 86-4127, 1986.

5) J.C. Bathurst, R.M. Li, and D.B. Simons, "Resistance Equation for Large-Scale Roughness." Journal of the Hydraulic Division, ASCE, Vol. 107, No. HY12, Proc. Paper 14239, December 1981, pp. 1593-1613.

6) A.G. Anderson, A.A. Painta, and J.T. Davenport, "Tentative Design for Riprap Lined Channels." National Cooperative Highway Research Program Report No. 108, Highway Research Board, National Academy of Sciences, Washington, DC, 1970.

7) S. Wang, H.W. Shen, "Incipient Sediment Motion and Riprap Design." Journal of the Hydraulics Division, ASCE, Vol. 111, No. 3, March 1985, pp. 520-538.